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INFLUENCE OF DROPLET SIZE ON SPRAY DEPOSITION AND WEED CONTROL USING GLYPHOSATE

Osmar G. T. M. Oliveira[1], Paulo R. M. Lopes[2], Carlos G. Raetano[3], Ronaldo C. Lima[2], Evandro P. Prado[2*]

[2*]Corresponding author. Universidade Estadual Paulista "Júlio de Mesquita Filho"/ Faculdade de Ciências Agrárias e Tecnológicas/ Dracena - SP, Brasil. E-mail: evandro.prado@unesp.br | ORCID ID: https://orcid.org/0000-0001-7616-0471

KEYWORDS

dose response, application technology, chemical control, spray deposits.

ABSTRACT

Droplet size is one of the most important factors that affect spray deposition and weed control through the use of herbicides. The aim of this study was to evaluate the influence of the droplet size on the spray deposition and control of *Euphorbia heterophylla* and *Urochloa ruziziensis* by using glyphosate. The treatments included spraying glyphosate with fine, medium, coarse, very coarse, and ultra-coarse droplet sizes to determine the deposition, uniformity of distribution, visual control, and dry weight reduction (DWR). The treatments were compared with the values of the dose required to achieve 50% DWR or 50% visual control (C50) at 7, 14, 21, and 28 days after herbicide application. Fine and medium droplet sizes afforded high deposition values and low distribution uniformities in *E. heterophylla*. Fine and medium droplet sizes yielded the lowest C50 on visual control and DWR in *E. heterophylla*, respectively. The droplet size did not affect the spray deposition on *U. ruziziensis* plants; however, the larger droplets had less uniformity of distribution. In *U. ruziziensis* plants, spraying glyphosate with coarse and medium droplet sizes yielded the lowest values of C50 to visual control and DWR, respectively.

INTRODUCTION

Chemical control is an essential practice for obtaining high yields in agricultural exploration, especially for intensive crops; however, its success is related to the quality of herbicide application.

Pesticide application programs are aimed at maximizing the amount of active ingredients deposited on the desired target, with uniform coverage to provide efficient control, and minimizing deposition in an off-target location. In most cases, meeting these requirements is challenging, as most applications are performed by fractionating the liquid into droplets, which can move away from the target (Grella et al., 2020).

The safe and environmentally friendly application of efficient and economical pesticides is a major concern and challenge for the agricultural sector, because pesticides can negatively impact non-target organisms (Dereumeaux et al., 2020). Thus, the optimization of these applications is essential for the efficient management of herbicides (Butts et al., 2018, 2019).

The analysis of the quantity and quality of the biologically active products deposited on the target is the first step toward successful herbicide management. Droplet size can influence the performance of biological control, depending on the herbicide and the morphological characteristics of the target (Ruas et al., 2011; Ferguson et al., 2018, 2019).

The deposition of the active ingredient on the targets can be optimized by the correct selection of spray nozzle (Ferguson et al., 2015; Farias et al., 2020). Nozzles are the main components of a spraying system and directly affect the efficiency of pesticides (Nuyttens et al., 2007). Many growers are skeptical of spray nozzles that spray coarse droplets, in addition to providing lower drift losses (Ferguson et al., 2015, 2016; Balsari et al., 2019) which helps reduce environmental contamination (Grella et al., 2020). However, coarse droplets may provide satisfactory control of some weed species if certain herbicides are used (Ferguson et al., 2018, 2019).

[1] Universidade Estadual Paulista "Júlio de Mesquita Filho"/ Faculdade de Engenharia/ Ilha Solteira - SP, Brasil.
[2] Universidade Estadual Paulista "Júlio de Mesquita Filho"/ Faculdade de Ciências Agrárias e Tecnológicas/ Dracena - SP, Brasil.
[3] Universidade Estadual Paulista "Júlio de Mesquita Filho"/ Faculdade de Ciências Agronômicas/ Botucatu - SP, Brasil.

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Coarse droplets cannot easily adhere to plant parts. They also provide a low coverage rate due to the tendency to ricochet (Balsari et al., 2017; Duga et al., 2017) or to fragment on impact with the leaf surface (Boukhalfa et al., 2014). This can lead to a decrease in the biological efficiency of the herbicides as the droplet size increases (Knoche, 1994; Smith et al., 2000; Creech et al., 2015), even for mobile herbicides such as glyphosate.

To address the disadvantages arising due to the drift process involving small droplets, researchers working in the field of Pesticide Application have attempted to optimize the control efficiency loss limit by increasing the droplet size. Thus, this topic has attracted significant research attention. It is hypothesized that glyphosate herbicide, which performs a systemic action, can offer satisfactory control efficiency even when applied in larger droplets, which are less prone to drift losses.

Therefore, the aim of this study was to evaluate the influence of droplet size on the spray deposition and control efficiency of *Euphorbia heterophylla* and *Urochloa ruziziensis* through the use of glyphosate.

MATERIAL AND METHODS

The experiments were conducted between April and October 2019 in a greenhouse at the Sao Paulo State University - College of Agricultural and Technological Sciences, Dracena Campus (latitude 21º27″ S, longitude 51º33" W, and average altitude 373 m).

Approximately five seeds each of *E. heterophylla* and *U. ruziziensis* (different pots) were sown at a depth of 0.5 to 1 cm in 0.8 L plastic pots (8 cm × 8 cm ×14 cm), with a potting mixture of sandy loam soil (81% sand, 7% silt, and 12% clay; pH 4.6) and substrate Carolina Soil® (3:1 w/w). After sowing, automatic micro-sprinkler irrigation was performed daily according to the plant needs. Seven days after emergence (DAE), the seedlings for each species were thinned to one uniformly sized plant per pot.

Nutritional supplementation was provided at 14 DAE for *U. ruziziensis* plants only, using 2.0 g per pot of a formulated mineral fertilizer (04-14-08). Furthermore, 4-5 leaves of *E. heterophylla* and 2-3 tillers of *U. ruziziensis* were sprayed. The choice of weed species is justified because they are morphologically distinct targets (monocotyledonous and dicotyledonous).

Quantification of spray deposition

The spray deposition values were analyzed in a completely randomized design using five treatments (fine, medium, coarse, very coarse, and ultra-coarse droplets), with 40 replicates each, represented by the pots of each plant species. A description of the treatments is shown in Table 1.

TABLE 1. Treatments used in spraying *E. heterophylla* and *U. ruziziensis* plants.

Treatments	Spray Nozzle	Nozzle angle/flow	Pressure (kPa)	Droplet class[a]	Droplet size[b] (micrometer)
T1	XR	11002	200	F	(145-225)
T2	XR	11002	100	M	(226-325)
T3	TT	11002	200	C	(326-400)
T4	AIXR	11002	200	VC	(401-500)
T5	TTI	11002	200	UC	(> 650)

[a]Droplet size information was provided by the manufacturers. [b]ASABE S-572.1; Classification (2009). F: fine, M: medium, C: coarse, VC: very coarse, UC: ultra-coarse.

Treatments were applied using a pressurized CO_2 back sprayer (Herbicat®), equipped with 4 nozzles spaced at 0.50 m apart travelling at 5.0 km h^{-1} for all treatments except for T2 which travelling at 3.5 km h^{-1}, delivering a spray volume of approximately 156 L ha^{-1}. The nozzles (Table 1) were held at a distance of 0.5 m from the top of the plants. The spray deposition values were determined using a spray solution of 1.5 g L^{-1} Brilliant Blue dye FCF (Brastókio®) and 2.5 L ha^{-1} (925 g ae ha^{-1}) glyphosate (Roundup DI®). Glyphosate was added to the spray solution to cater for the possible physicochemical modification provided by the herbicide, which could influence spray deposition.

After treatment application and drying of the solution (approximately 5 min), the plants were cut at a position above the ground, placed in plastic bags, and washed with 100 mL of deionized water to remove the dye. The solution containing the dye was placed in 70 mL plastic containers and stored in the dark until absorbance determination. After washing, the plants were placed in paper bags and oven-dried at 65 °C for 72 h, and the dry weight (DW) was determined using an analytical balance (Marten, model AY220).

The amount of dye deposited on the plants was quantified using a spectrophotometer (Biospectrum, model SP 220) at a wavelength of 630 nm (Prado et al., 2015; Nairn & Forster, 2019; Godinho Jr., 2020). A linear equation was established ([dye] = 7.235 × Abs + 0.0263; R^2 = 0.99) using the previously known dye concentrations of 15, 7.5, 3.75, 1.875, 0.9375, 0.4688 and 0.2343 mg L^{-1}, which allowed for the transformation of the absorbance values into dye concentrations (in mg L^{-1}).

Using the dye concentration values in the solution, dye concentration detected by the spectrophotometer, and sample dilution volume, the volume retained by the target could be established.

$$V1 = \frac{C2 \times V2}{C1} \quad (1)$$

Where:

C1 = initial dye concentration in the spray solution (mg L^{-1});

V1 = volume retained on the target (mL);

C2 = concentration detected by the spectrophotometer (mg L^{-1}),

V2 = sample dilution volume (mL).

The volume retained by each plant (mL) was transformed into microliters and divided by its respective DW to obtain the volume in μL g^{-1} DW. The deposition data were submitted to analysis of variance and means compared by the Scott-Knott test at 5% probability.

To determine the uniformity of spray deposition distribution for each treatment, the data obtained were standardized, ordered, and used to calculate the normal probability distribution (Gaussian distribution) using the formula $\int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} e^{\left(-\frac{x^2}{2}\right)}$. The data were used to adjust logistic regression using [eq. (2)].

$$Y = \frac{a}{1 + e^{b-cx}} \quad (2)$$

Where:

a: maximum curve asymptote;

b: curve displacement along the x axis (value in modulus);

c: curve slope,

x: deposition data.

To represent the cumulative distribution frequency of spray deposition, we adopted an approximate value of 1 for the maximum curve asymptote. In general, the displacement of the curve along the x-axis is represented by the module of parameter "b," and the inflection point is represented by the parameter "c." Logistic accuracy was assessed using the determination coefficient (R^2). The data were analyzed using R statistical software (R Development Core Team, 2017).

Dose-response curves for *E. heterophylla* and *U. ruziziensis* when sprayed with glyphosate herbicide with different droplet sizes

The dose-response curves of the plants were determined in a completely randomized experimental design using a 5 × 8 factorial scheme, with five spray droplet size classes (fine, medium, coarse, very coarse, and ultra-coarse) and eight herbicide concentrations, totaling to 40 treatments. These treatments were applied in quadruplicate for *E. heterophylla* and *U. ruziziensis*.

Considering a glyphosate label dose of 925 g ae ha^{-1} (Roundup Original DI) to control *E. heterophylla* and *U. ruziziensis*, the eight concentrations used were 0, 11, 34, 103, 308, 925, 2.775 and 8.325 g ae ha^{-1}. The spraying was carried out using the same equipment and operating conditions used in the spray deposition experiment, except for the use of a spray boom with two spray nozzles spaced 0.5 m apart. A description of the treatments (spray tips) is presented in Table 1. After treatment application, the pots were placed in a greenhouse for 24 h without irrigation. Subsequently, they were irrigated based on the plant needs.

At 7, 14, 21, and 28 days after application (DAA) of the glyphosate, visual evaluations of the control percentage were carried out based on vigor, chlorosis, necrosis, and plant death. The evaluation results were compared to those of the control treatment (without herbicide application). Using these data, scores were assigned using a scale ranging from 0%, when there was no phytotoxic effect, to 100%, when the plants were dead.

After the last control evaluation (28 DAA), the plants of each species were harvested at a position above the ground, placed in a paper bag, and oven-dried at 65 °C for 72 h. The DW was determined using an analytical balance (Marten, model AY220).

The DW data were transformed into dry weight reduction (DWR) data by comparison with control treatment data according to [eq. (3)]:

$$\mathrm{DWR} = \left(\frac{\mathrm{C} - \mathrm{T}}{\mathrm{C}}\right) \times 100, \quad (3)$$

Where:

DWR: dry weight reduction;

C: mean of the four-control DW,

T: individual DW of plants treated with glyphosate.

Data percentages for visual control and DWR were analyzed using a non-linear regression to determine the amount of glyphosate needed to provide 50% of visual control or 50% DWR for *E. heterophylla* and *U. ruziziensis*. A four-parameter log-logistic equation (Equation 4) was used (Ritz et al., 2015).

$$\mathrm{Y} = \frac{\mathrm{D} - \mathrm{C}}{1 + \exp\{\mathrm{b}[\log(\mathrm{X}) - \log(\mathrm{C50})]\}} + \mathrm{C} \quad (4)$$

Where:

Y: plant response;

X: herbicide dose (g ae ha^{-1});

D: curve upper limit;

C: curve lower limit;

b: curve slope of C50,

C50: dose (g ae ha^{-1}) required to reduce 50% of DW or provide 50% of visual control.

The analysis of the dose-response curve and determination of the C50 values were performed using the *drc* package in R software (R Development Core Team, 2017). The ANOVA function was used to perform the lack-of-fit test, and a P-value ≥ 0.05 was considered an acceptable description of the data by the fitted non-linear model (Ritz & Streibig, 2012; Ritz et al., 2015).

Meteorological conditions at the time of application

Meteorological data of temperature, air relative humidity, and wind speed were recorded during the four application scenarios, as listed in Table 2. The data were recorded by an automatic meteorological station (Campbell Scientific Datalogger-model CR10X) installed approximately 300 m away from the application site.

TABLE 2. Meteorological conditions at the time of spraying during the deposition and dose-response experiments.

Meteorological data	DE	DU	DRE	DRU
Temperature (°C)	31±3	27±3	23±2	28±2
Relative humidity (%)	54±5	60±5	50±5	40±5
*Wind speed (km h^{-1})	2	5	3	3
Application date	15/03/18	10/05/19	26/06/19	29/07/19

*Maximum wind speed recorded at a weather station outside the greenhouse. Source: Campbell Scientific Automatic Meteorological Station, Datalogger CR10X model – FCAT/Unesp, Dracena-SP, 2019. DE: Deposition *E. heterophylla*/ DU: Deposition *U. ruziziensis*/ DRE: Dose response *E. heterophylla*/ DRU: Dose response *U. ruziziensis.*

RESULTS AND DISCUSSION

Spray deposition quantification

Spray deposition values of *E. heterophylla* and *U. ruziziensis* plants, sprayed with glyphosate associated with the Brilliant Blue dye with different droplet sizes are provided in Table 3.

TABLE 3. Deposition values on *Euphorbia heterophylla* and *Urochloa ruziziensis*, expressed in microliters per gram of the dry weight (DW), after spraying with different droplet sizes.

Droplet size	*E. heterophylla*	*U. ruziziensis*
	Spray deposits (µL g^{-1} DW)	
Fine	77.2 a	152.5 a
Medium	82.0 a	154.9 a
Coarse	51.0 b	146.7 a
Very coarse	55.7 b	162.3 a
Ultra-coarse	46.1 b	163.6 a

Means followed by the same letter do not differ from each other according to the Scott-Knott test at 5% probability.

High spray deposition values were observed on *E. heterophylla* plants when sprays with fine and medium droplets were used. These values which differed significantly (F: 42.1; P < 0.001; CV: 25.0%) from treatments with coarse, very coarse, and ultra-coarse droplets (Table 3). Tokura et al. (2013) reported high deposition values on *E. heterophylla* plants when spraying was carried out using very fine and fine droplets and using lower values for very coarse droplets, corroborating the results obtained (Table 3).

The higher deposition values observed when spraying fine and medium droplets on *E. heterophylla* is probably associated with the characteristics of plant leaves with high epicuticular wax content, high laticifer density, and large adaxial surface cuticle thickness (Ferreira et al., 2003). Leaf surfaces with high wax content are difficult to wet, making droplet retention difficult due to a greater probability of bounce or shatter after impact on the leaf surface (Smith et al., 2000; Massinon et al., 2017), especially for those with larger diameters (Smith et al., 2000).

There was no significant difference (F = 0.85, P = 0.492, CV = 30.7%) in the spray deposition on *U. ruziziensis* plants for the different droplet sizes (Table 3). Similar results were reported in a study by Rodrigues-Costa et al. (2012). This previous study did not find significant differences in the deposition on *Brachiaria plantaginea* plants at the 3-5 tiller stage, which were sprayed with different spray nozzles and droplet sizes, delivering a spray volume of 150 and 200 L ha^{-1}. Furthermore, Tokura et al. (2013) did not find a significant difference in the spray deposition on *B. plantaginea* plants between fine, medium, and very coarse droplet sizes sprayed by flat fan nozzles.

Distinct spray deposition results were observed between the two weed species studied (Table 3). The major factors affecting leaf droplet retention are the morphological characteristics of the plants, pesticide formulation, and characteristics of the spray process, such as the droplet size and velocity (Smith et al., 2000; Creech et al., 2015; Massinon et al., 2017), which can result in different results depending on the combination.

The parameter estimates for the logistic model that describes the deposition of the spray solution on *E. heterophylla* and *U. ruziziensis* are presented in Table 4. Apart from the fine droplets on *U. ruziziensis*, all other droplet sizes produced a uniformity coefficient equal to or greater than 0.92, demonstrating a good curve fit.

TABLE 4. Parameter estimates for the logistic model, describing spray deposition on *E. heterophylla* and *U. ruziziensis* plants, when sprayed with different droplet sizes.

Equation parameters[a]	Droplet size									
	Fine		Medium		Coarse		Very coarse		Ultra-coarse	
	E	U	E	U	E	U	E	U	E	U
a	1.01	1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
b	6.71	5.88	6.60	5.54	6.62	5.23	7.41	5.02	6.46	5.17
c	0.085	0.038	0.080	0.036	0.110	0.035	0.100	0.031	0.139	0.031
R^2	0.98	0.86	0.96	0.94	0.96	0.92	0.97	0.94	0.95	0.94

E: *Euphorbia heterophylla*; U: *Urocloa ruziziensis*

[a] $\mathbf{Y} = \frac{\mathbf{a}}{\mathbf{1+e^{b-cx}}}$

Greater uniformity of spray deposition distribution was observed in *E. heterophylla* plants when sprayed with ultra-coarse droplets, evidenced by the highest value of the "c" parameter (0.139), followed by coarse (0.110), very coarse (0.100), fine (0.085) and medium (0.080) droplets (Table 4). Good distribution uniformity of the herbicide solution on weeds is fundamental for greater control effectiveness. Non-uniform deposition implies that plants receive less or more deposition than required. Inadequate deposition of the herbicide solution on plants can result in control failures. However, an amount above the desired dose will result in wastage and increase the risk of environmental contamination.

The highest values of the "c" parameter for *U. ruziziensis* (Table 4) were observed in treatments involving fine droplets (0.038), followed by medium (0.036), coarse (0.035), very coarse, and ultra-coarse (0.031). Lower distribution uniformity on both weeds was observed in treatments that received the highest deposition values, regardless of the droplet size (Tables 3 and 4). The increase in variability was related to the higher mean deposition values in these treatments.

The accumulated frequency of deposition on *E. heterophylla* and *U. ruziziensis* plants sprayed with different droplet sizes is shown in Figure 1. Figure 1a shows a greater curve slope in treatments with coarse and very coarse droplets (higher "c" parameter in Table 4), when compared to the curves of fine and medium droplet sizes in *E. heterophylla*. For *U. ruziziensis*, the greatest curve slopes were obtained for the treatments with the smallest droplet sizes (Figure 1b).

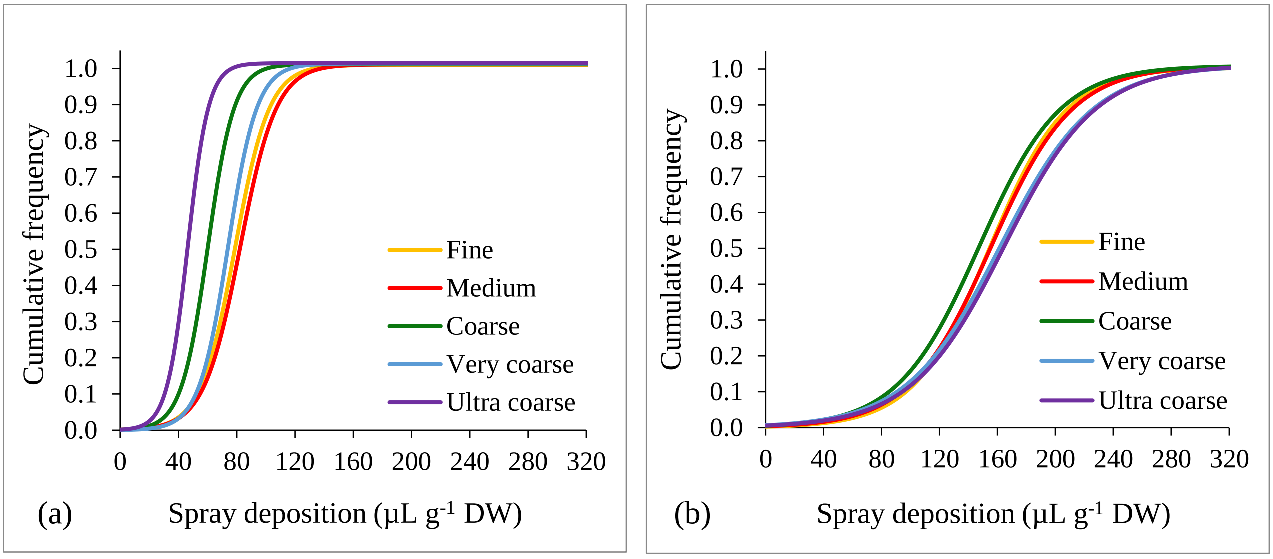

FIGURE 1. Cumulative frequency of spray deposition (µL g^{-1} DW) provided by different droplet sizes on *E. heterophylla* (a) and *U. ruziziensis* (b) plants, using the logistic model.

Although the curves from treatments with very coarse and ultra-coarse droplets provided better uniformity of spray deposition on *E. heterophylla* plants (Figure 1), these treatments yielded the lowest spray deposition values (Table 3). This is evident when observing the curves of fine and medium droplets, which are placed to the right of the very coarse and ultra-coarse droplet size curves (Figure 1a). Therefore, it was found that the increase in the droplet size resulted in higher deposition values for *E. heterophylla* but with a lower uniformity deposition.

The cumulative frequency curves obtained for *U. ruziziensis* plants presented similar shapes, and the curves for treatments applied with smaller droplets were slightly sloped compared to those with very coarse and ultra-coarse droplet sizes (Figure 1b).

Likewise, Costa et al. (2008) also reported less uniformity and greater deposition of the spray solution on *Brachiaria brizantha* plants, when sprayed with air induction nozzles with extremely coarse droplets. The uniformity of spray solution deposition is highlighted as a relevant factor in the performance of pesticides (Rodrigues-Costa et al., 2012), since an insufficient amount of deposition on the target can result in control failures.

Dose-response curves for *E. heterophylla* and *U. ruziziensis* when sprayed with glyphosate herbicide with different droplet sizes

According to the results of the lack-of-fit test (P > 0.05; F test), there were no significant differences in the DWR curves and percentage of visual control for *E. heterophylla* (Table 5) and *U. ruziziensis*, except for the visual assessment at 7 DAA (Table 6), with P values > 0.05, indicating satisfactory model fit (Ritz & Streibig, 2012; Ritz et al., 2015).

The estimates of the parameters obtained from the log-logistic regression that describes the visual control and DWR of *E. heterophylla* plants when glyphosate was applied in different droplet sizes are described in Table 5.

TABLE 5. Log-logistic regression parameters and C50 values (± SE) that describe the visual control and dry weight reduction in *E. heterophylla* plants sprayed with glyphosate of different droplet sizes.

DAA	Parameters	Droplet size				
		Fine	Medium	Coarse	Very coarse	Ultra-coarse
		Visual control (%)				
7	B	-2.5	-1.4	-2.5	-1.8	-12.6
	C	0.52	0.52	0.52	0.52	0.52
	D	56.5	56.5	56.5	56.5	56.5
	C50	612(74)	784(121)	777(99)	1134(150)	1069(186)
	Lack of fit	0.8560 (NS)				
14	B	-4.2	-3.1	-3.1	-3.4	-6.5
	C	1.2	1.2	1.2	1.2	1.2
	D	92.3	92.3	92.3	92.3	92.3
	C50	500(35)	764(41)	656(37)	747(42)	969(106)
	Lack of fit	0.9008 (NS)				
21	B	-3.1	-2.6	-2.3	-1.8	-2.8
	C	0.8	0.8	0.8	0.8	0.8
	D	101.2	101.2	101.2	101.2	101.2
	C50	430(24)	520(30)	516(31)	662(44)	618(36)
	Lack of fit	0.8466 (NS)				
28	B	-3.8	-1.7	-1.6	-2.5	-2.5
	C	1.8	1.8	1.8	1.8	1.8
	D	101.9	101.9	101.9	101.9	101.9
	C50	444(63)	539(80)	612(93)	558(71)	737(89)
	Lack of fit	0.8854 (NS)				
		Dry weight reduction (%)				
28	B	-0.5	-0.5	-0.7	-0.6	-1.2
	C	1.3	1.3	1.3	1.3	1.3
	D	91.7	91.7	91.7	91.7	91.7
	C50	49(12)	38(10)	58(13)	107(24)	225(30)
	Lack of fit	0.9941 (NS)				

Note. C50 is the glyphosate dose required to provide 50% visual control or 50% dry weight reduction. DAA: days after application. DWR: Dry weight reduction NS: not significant

Very coarse and ultra-coarse droplet sizes yielded the highest C50 values for the visual control of *E. heterophylla* plants in all periods evaluated. The same behavior was observed in the DWR with higher C50 values for ultra-coarse droplet applications (Table 5).

As observed in Table 5, the C50 values increased with an increase in droplet size. In the DWR, there was an almost 6-fold increase between the treatments with medium (38 g ae ha^{-1}) and ultra-coarse (225 g ae ha^{-1}) droplet sizes. It is evident that glyphosate visual control in *E. heterophylla* plants can be compromised by spraying very coarse and ultra-coarse droplets. The increase in C50 values for visual control may be related to the smaller deposition provided by the larger diameter droplets (Table 3). Thus, spray application aimed at controlling *E. heterophylla* with an ultra-coarse droplet size, even when using systemic herbicides such as glyphosate, should be avoided because of the possibility of failure.

Since fine droplets are more prone to drift (Ferguson et al., 2015, 2016; Balsari et al., 2019) there is a possibility of spraying the herbicide glyphosate with (a) larger droplets on the borders of the area to be treated, especially when they are adjacent to areas cultivated with susceptible species and (b) smaller droplets inside the crop area where adverse effects of drift can be minimized (Stainier et al., 2006). Thus, other parameters, such as the application volume, adjuvant tank mixtures, herbicides, and meteorological conditions at the time of spraying, must be considered when choosing the appropriate droplet size.

The estimates of the parameters obtained from the log-logistic regression that describes the visual control and DWR of *U. ruziziensis* plants when glyphosate was applied in different droplet sizes are described in Table 6.

TABLE 6. Log-logistic regression parameters and C50 values (± SE) that describe the visual control and dry weight reduction in *U. ruziziensis* plants sprayed with glyphosate of different droplet sizes.

DAA	Parameters	Droplet size				
		Fine	Medium	Coarse	Very coarse	Ultra-coarse
		Visual control (%)				
7	B	-4.8	-3.7	-1.3	-3.6	-5.1
	C	-0.1	-0.1	-0.1	-0.1	-0.1
	D	95.5	95.5	95.5	95.5	95.5
	C50	367(47)	318(15)	167(17)	287(15)	309(10)
	Lack of fit	P= 0.0003				
14	B	-2.7	-2.2	-1.5	-3.2	-7.8
	C	-0.5	-0.5	-0.5	-0.5	-0.5
	D	95.3	95.3	95.3	95.3	95.3
	C50	275(21)	228(21)	108(13)	219(19)	272(22)
	Lack of fit	P= 0.0534 (NS)				
21	B	-1.9	-2.0	-4.3	-3.9	-6.9
	C	-0.2	-0.2	-0.2	-0.2	-0.2
	D	95	95	95	95	95
	C50	196(20)	177(18)	75(9)	157(17)	252(51)
	Lack of fit	P= 1.0000 (NS)				
28	B	-1.9	-2.4	-5.0	-2.8	-3.3
	C	-0.5	-0.5	-0.5	-0.5	-0.5
	D	99.6	99.6	99.6	99.6	99.6
	C50	166(20)	143(15)	68(12)	144(15)	215(24)
	Lack of fit	P= 1.0000 (NS)				
		Dry weigh reduction (%)				
28	B	-3.3	-2.9	-6.8	-1.3	-1.5
	C	-0.3	-0.3	-0.3	-0.3	-0.3
	D	72.0	72.0	72.0	72.0	72.0
	C50	158(30)	73(13)	94(22)	155(40)	149(35)
	Lack of fit	P= 0.8912(NS)				

Note. C50 is the glyphosate dose required to provide 50% visual control or 50% dry weight reduction. DAA: days after application. DWR: Dry weight reduction NS: not significant

In *U. ruziziensis* plants, the lowest C50 values of the visual control were found with coarse droplet size applications for all the evaluated periods (Table 6). For the DWR, lower C50 values were observed when medium (73 g ae ha^{-1}) and coarse (94 g ae ha^{-1}) droplets were applied. In contrast, spraying of fine and ultra-coarse droplets yielded higher C50 values (Table 6). Therefore, the use of fine droplets is evidently not the most suitable technique for *U. ruziziensis* control, since lower control and drift losses may occur, especially under unfavorable meteorological conditions.

Although no significant differences in spray deposition were detected in *U. ruziziensis* plants, the lowest C50 values found with medium and coarse droplets may have occurred because of other factors not observed in this study, or because the herbicide phytotoxicity is not related to the amount of spray deposition on the plants. It should be noted that the deposition study was carried out at different periods from the control study, and morphological plant characteristics may have varied with the environmental conditions.

A higher C50 value obtained with a reduced DW of *U. ruziziensis* plants when sprayed with fine droplets may be related to the meteorological conditions at the time of application (Table 2), especially at low relative humidity (40±5%), which may have provided less wetness time on the leaves and consequently decreased herbicide absorption and translocation.

Similar results were reported by Ferguson et al. (2019), who observed a higher dry weight reduction of *Chloris* spp. when sprayed with coarse droplets. Ferguson et al. (2018) also reported greater weed control efficacy for a broad group of herbicide modes of action using coarse droplets, in addition to reducing the potential risk of drift compared to fine droplet sprays.

When aiming for good control performance (≥ 80%) of *E. heterophylla* and *U. ruziziensis* plants while minimizing drift losses simultaneously, the use of nozzles that provide coarse droplets may be a suitable for glyphosate application. It is noteworthy that the spray volume applied in this study was 156 L ha^{-1} and spraying coarse droplets in reduced spray volumes may decrease coverage and the efficacy of glyphosate. Butts et al. (2018) found reductions in the effectiveness of weed control with increasing droplet diameter in the herbicides dicamba and glufosinate, especially in smaller volumes. The same authors reported the extreme complexity of the herbicide application process, with multiple variables impacting its effectiveness.

Finally, there seems to be no consensus in choosing the ideal droplet size, as there are many variables, such as the species of plants, herbicide mode of action, plant resistance to the herbicide, and meteorological conditions at the application time, among others that can play, individually or in combination, a relevant role in weed control. New studies must be conducted to improve the understanding of this process.

CONCLUSIONS

Fine and medium droplet sizes afforded the highest deposition values and the lowest distribution uniformity in *E. heterophylla* plants. Spraying glyphosate on *E. heterophylla* plants using fine and medium droplet sizes yielded the lowest C50 values for visual control and DWR, respectively.

Droplet size did not interfere with spray deposition on *U. ruziziensis* plants, but larger droplet sizes yielded low distribution uniformity. In *U. ruziziensis* plants, spraying glyphosate with coarse and medium droplet sizes afforded the lowest C50 values for visual control and DWR, respectively.

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